Conference summary

Synchrotron light
of the third and fourth generation
- how to fill the generation gap

Friso van der Veen
Paul Scherrer Institut,
Villigen, Switzerland

SRI, San Francisco, August 25-29, 2003

What have we learnt at this conference?

- that Howard Padmore and Joe Stöhr have put together an excellent conference program

Howard

Joe

Thanks !

- that many presentations were of such a high level, that a *summary* of them is bound to fail.

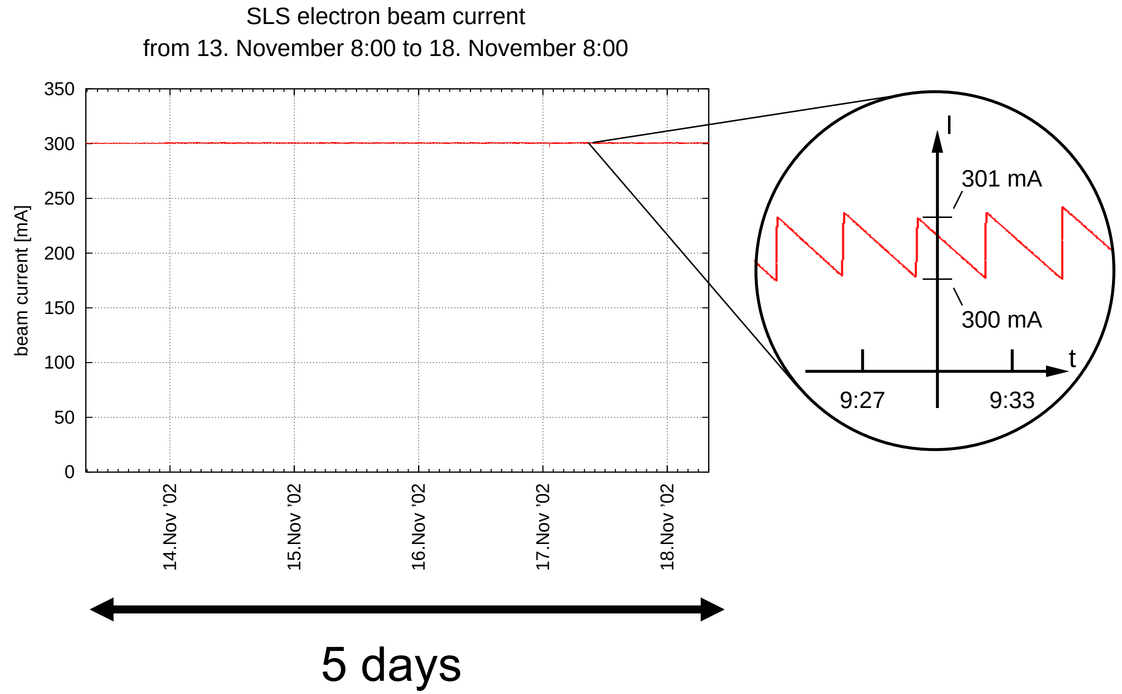
I will fail !

Structure of the talk

- 3rd generation sources, FEL and ERL schemes
- Ultrashort X-ray pulses
  Time dependent processes
- Optics
  Microscopy, imaging
- Coherence
  Lensless imaging, interferometry, dynamical properties of matter
- Improved detection schemes
  We keep talking about it, but do too little !

Increased beam stability

Top-up injection at the SLS:



Top up also at APS and at future/upgraded sources

Top-up injection → position stability

Position stability (σ)

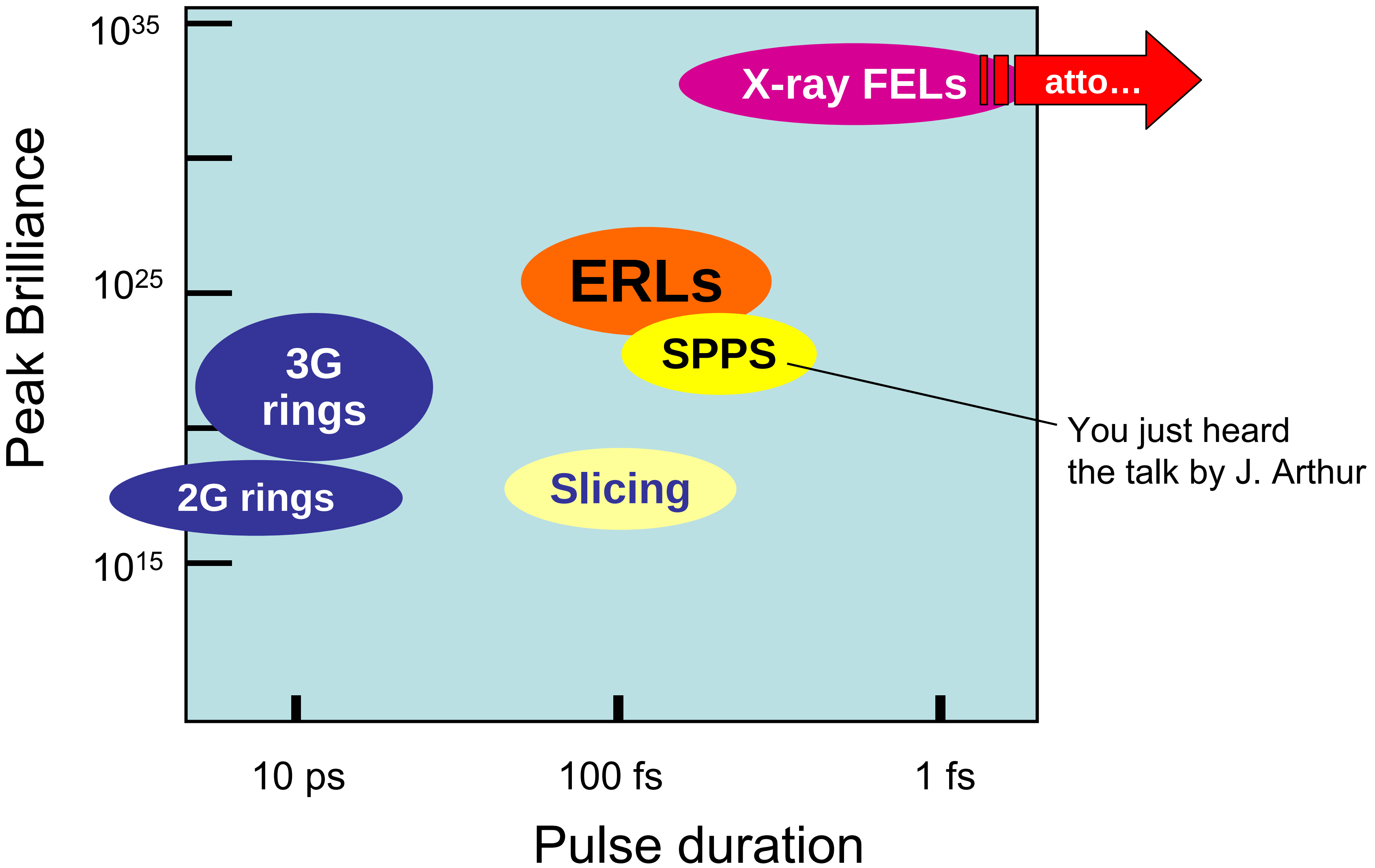
100 s:	30 nm
20 days:	0.5 μm
Year:	1-2 μm

Energy stability ~10^{-5}

Correcting the average hor. orbit by adjusting the RF-frequency

FEL and ERL schemes

J. Hastings, T. Shintake, S. Gruner, many posters



Reduction of the gun emittance could strongly reduce the dimension of a FEL

$$\varepsilon \leq \frac{\lambda}{4\pi}$$

- FOR DIFFRACTION LIMITED BEAM

$$\varepsilon_N = \varepsilon\beta\gamma \rightarrow \gamma \geq \frac{4\pi\varepsilon_N}{\lambda}$$

- FOR REDUCED LINAC ENERGY

$$\rho^3 \approx \frac{I_{peak}\lambda}{\varepsilon\gamma^2}$$

- FOR HIGHER FEL GAIN

$$\lambda_U = \lambda \frac{2\gamma^2}{1 + K^2/2}$$

- FOR SHORTER UNDULATOR LENGTHS

A possible way to reduce the emittance

Field emission gun

L. Rivkin

FIELD REQUIREMENTS ~ 5 V/nm → 5 GV/m

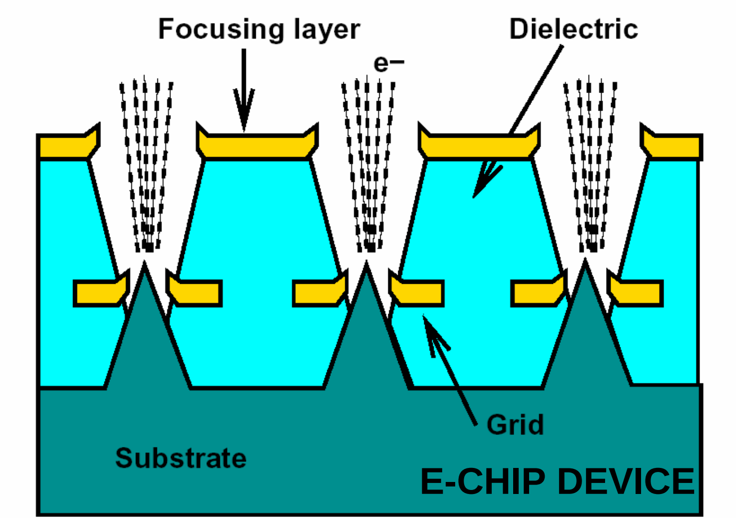
FIELD ENHANCEMENT OF A TIP:

$$E_{tip} = \frac{V}{k\,r}$$

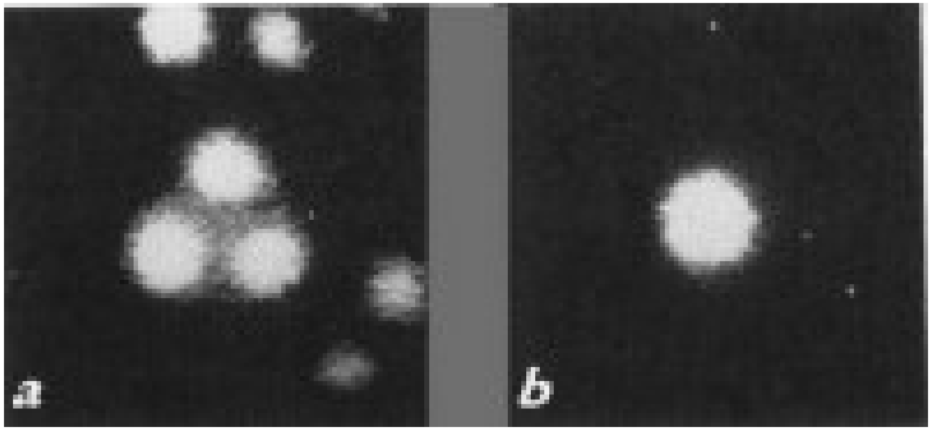
for k~5,

tip apex radius r=100 nm

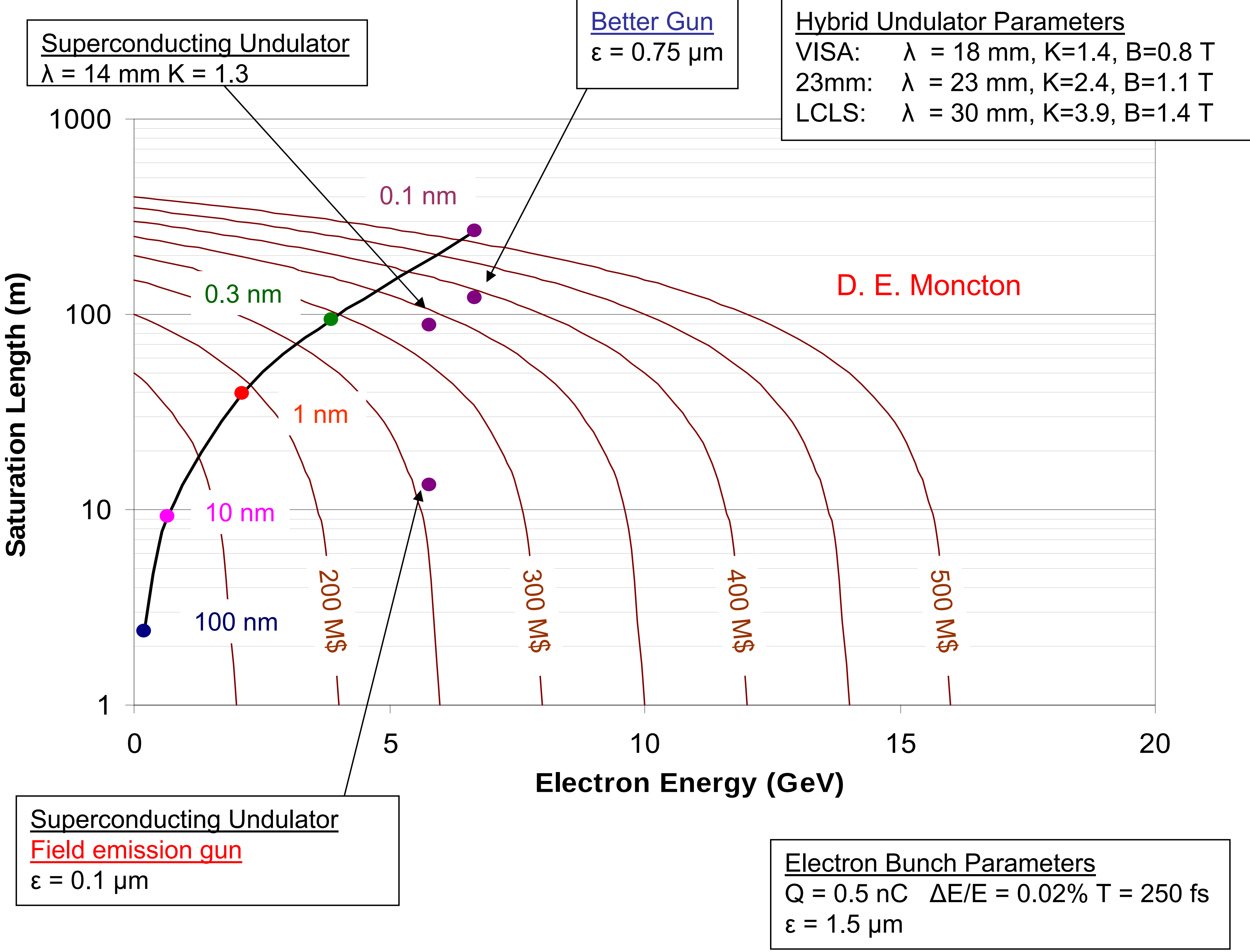
→ V ~ 2kV



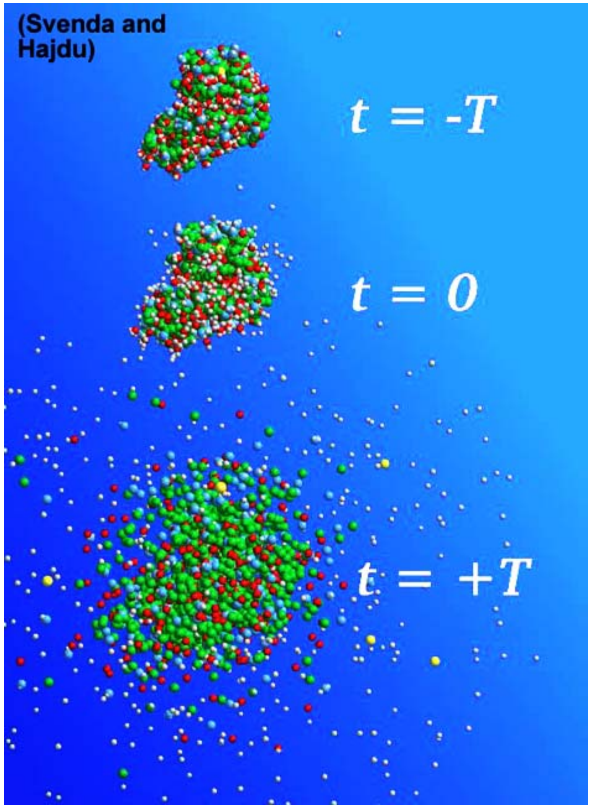
Generic field emitter array



Ultimate smallest tip built up by 4 tungsten atoms / H.-W. Fink, ETHZ


Superconducting Undulator
λ = 14 mm K = 1.3
Better Gun
ε = 0.75 μm
Hybrid Undulator Parameters
VISA: λ = 18 mm, K=1.4, B=0.8 T
23mm: λ = 23 mm, K=2.4, B=1.1 T
LCLS: λ = 30 mm, K=3.9, B=1.4 T
1000
100
10
1
Saturation Length (m)
0.1 nm
0.3 nm
1 nm
10 nm
100 nm
D. E. Moncton
200 M$
300 M$
400 M$
500 M$
0
5
10
15
20
Electron Energy (GeV)
Superconducting Undulator
Field emission gun
ε = 0.1 μm
Electron Bunch Parameters
Q = 0.5 nC ΔE/E = 0.02% T = 250 fs
ε = 1.5 μm

Use fs pulses for, e.g., lensless imaging of proteins



How long does it take for the molecule to fly apart?

S. Hau-Riege at Satellite Workshop on X-ray Science with Coherent Radiation:

Only about 4 fs!

→ Need coherent control in the time domain

↓

Seeded FEL
or ERL

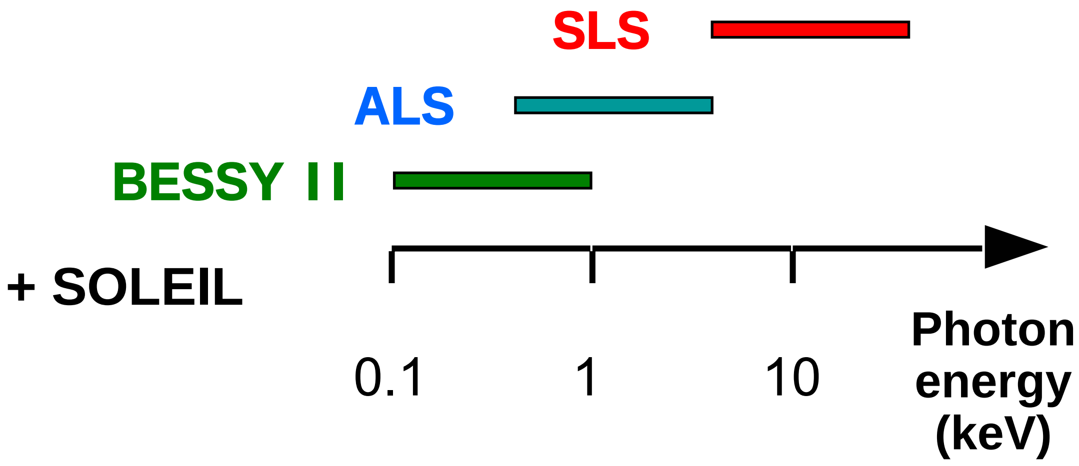
More calculations of X-ray/matter interaction required

In the meantime: femtosecond electron beam slicing

R.W.Schoenlein et al.
Science 287 (2000), 2237

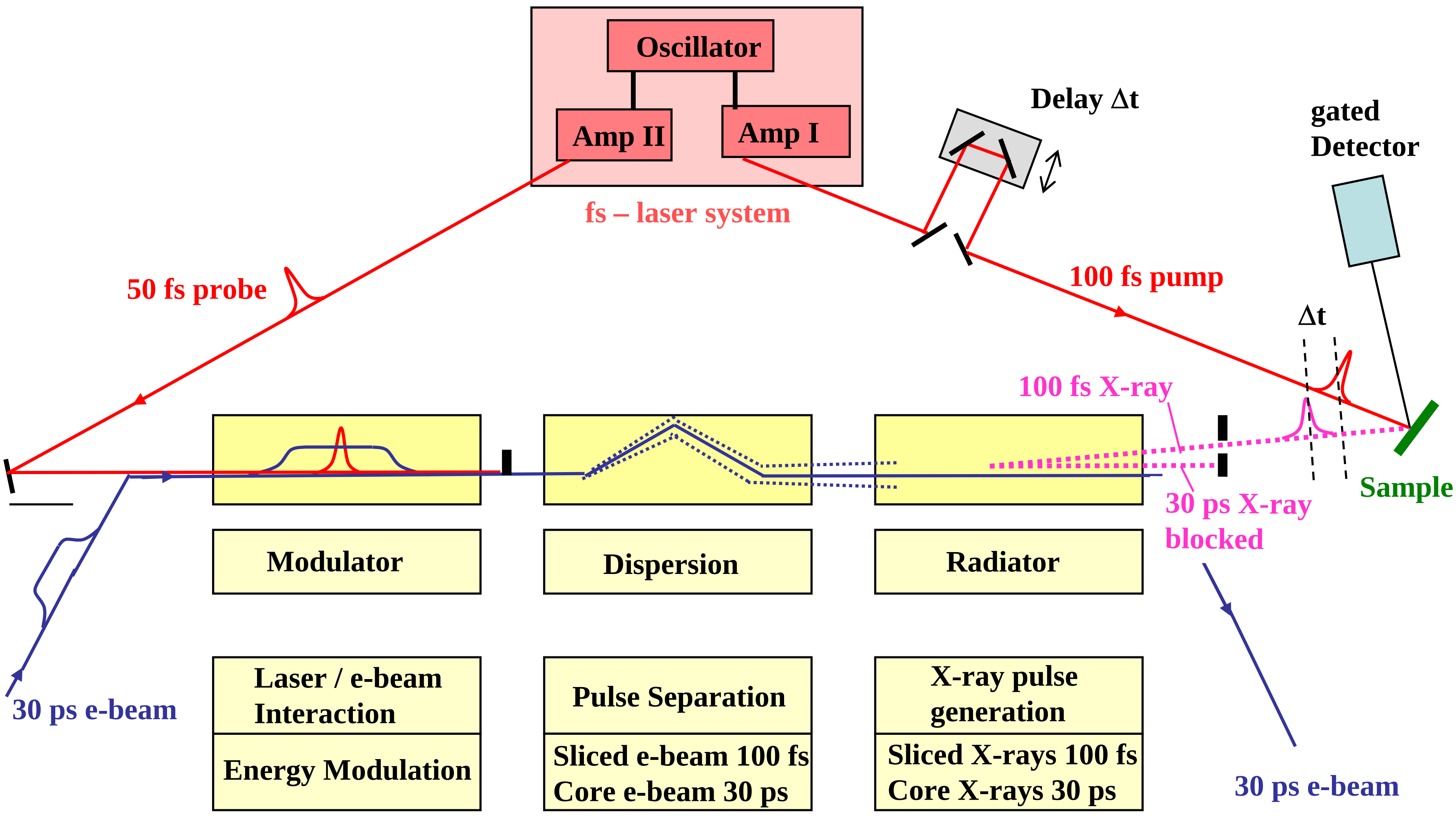
First taste of short pulses for experiments

- Use high pulse energy, fs lasers technology
- Undulator radiators
- $10^2 - 10^4$ photons per pulse (low efficiency)

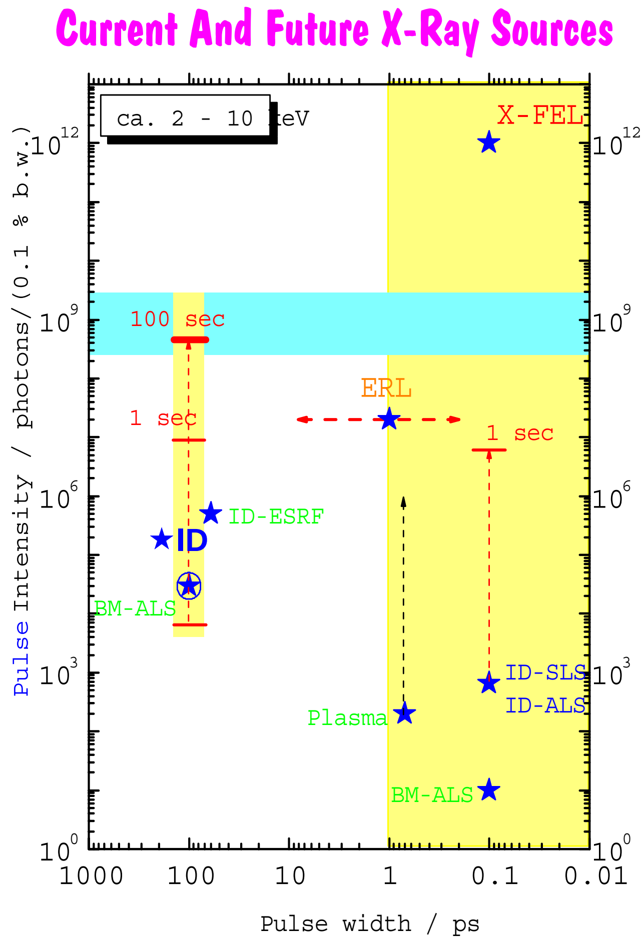


G. Ingold et al

Beam slicing at the SLS



Intensities?



With pump-probe techniques one can accumulate signal. That helps.

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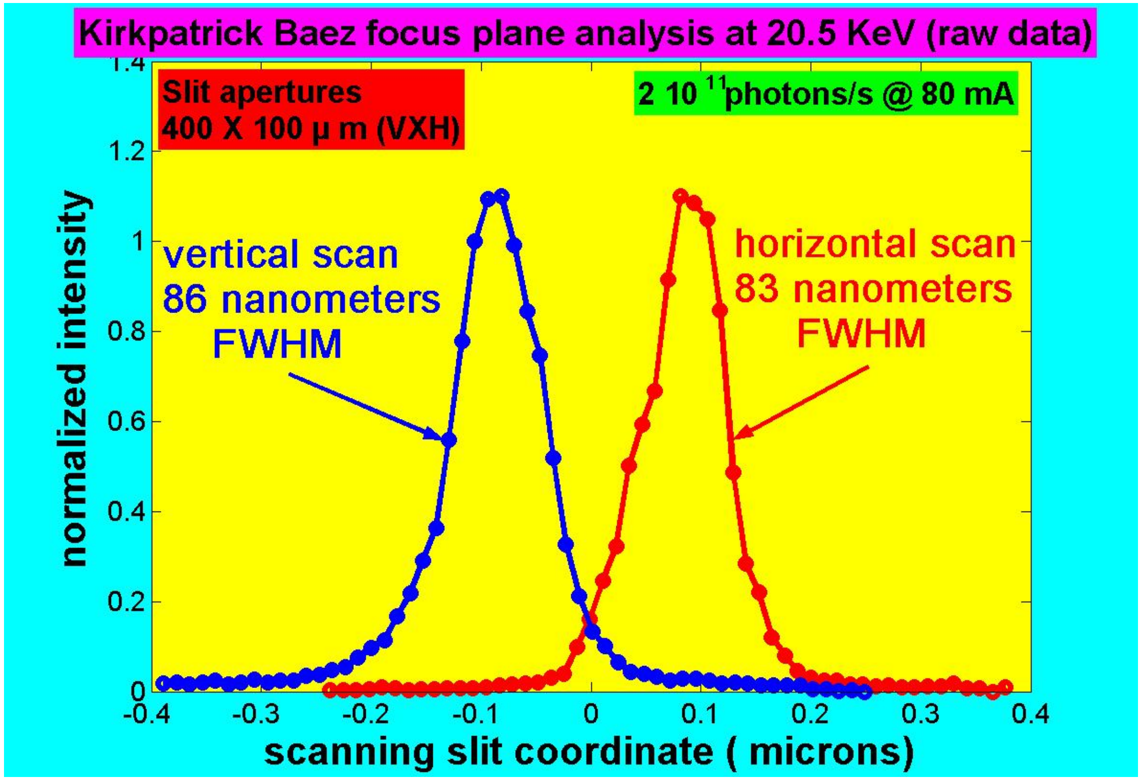
Making small beam spots

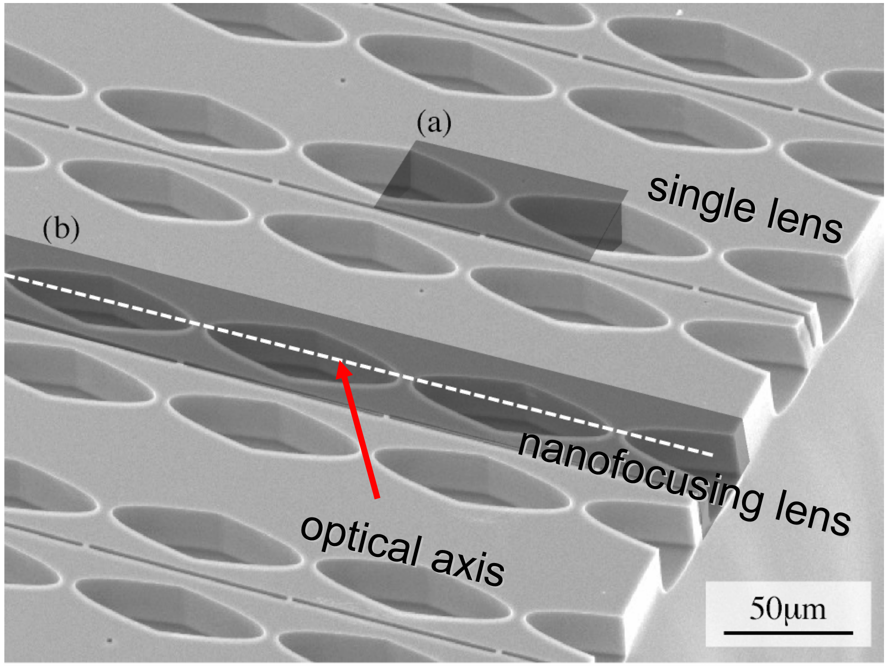


P. Cloetens, C. Rau, C. Liu, A. Takeuchi, and others

Kirkpatrick-Baez optics:

- Achromatic
- Spot size is getting close to the diffraction limit $\lambda/(2 \cdot NA)$
- Alignment can be difficult

Refractive lenses



extreme curvature:

R = 1µm - 3µm

N = 50 - 100

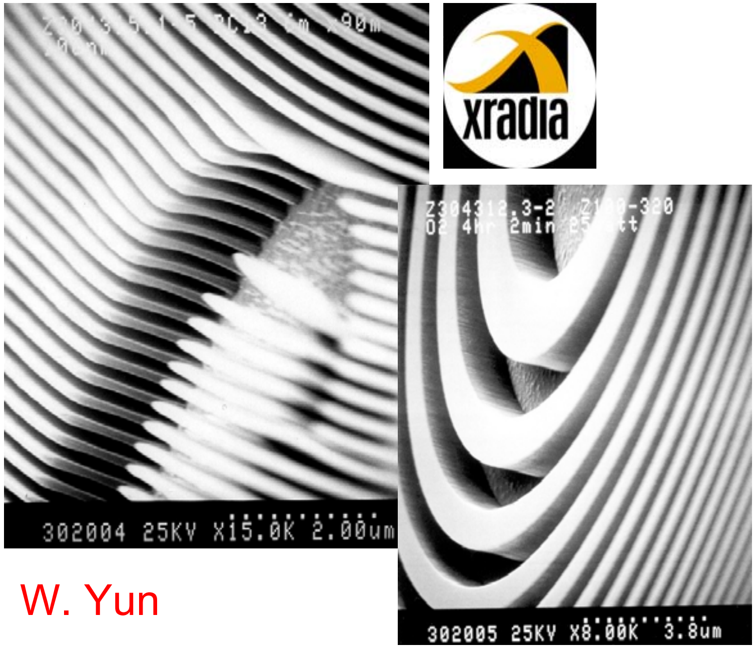
Schroer et al.,
APL 82, 1485 (2003)

Refractive lenses:

- Chromatic
- Once installed, robust
- Much used for higher X-ray energies
- Can now be made out of ‘plastic’
- Effective numerical aperture limited by Compton scattering

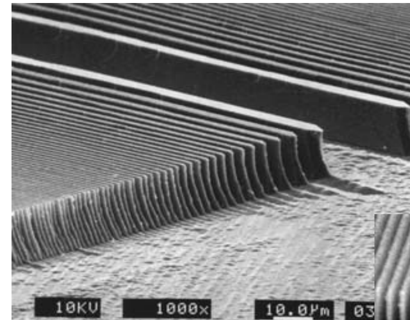
V. Nazmov, I. Snigireva, S.D. Shastri, and others

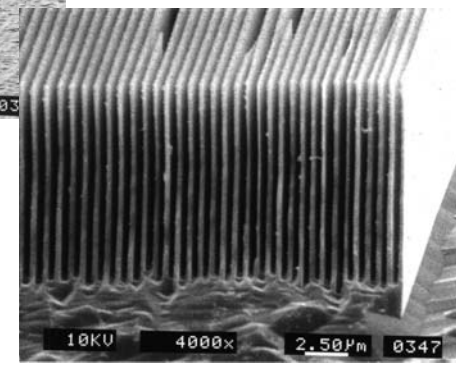
Fresnel zone plates



W. Yun

Center and outer zones of a zone plate with 50 nm outer zone width and 700 um thickness.





C. David
1D FZP for hard X-rays

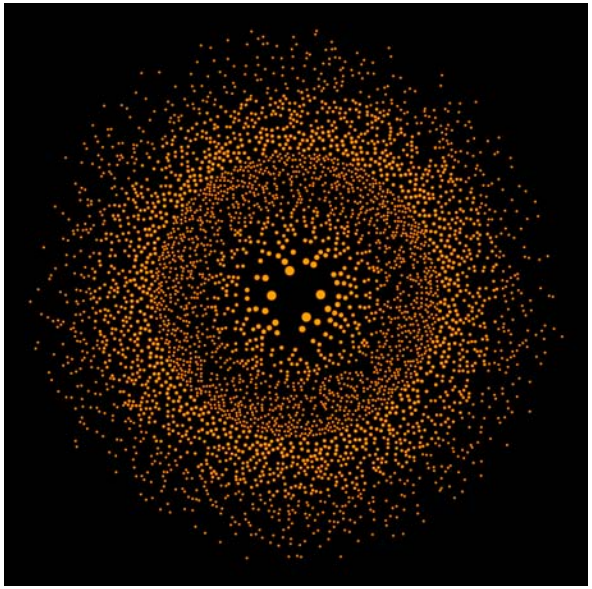
Fresnel zone plates:

- Chromatic
- Soft X-ray microscopy
- Now also for hard X-rays (zones in anti-phase)

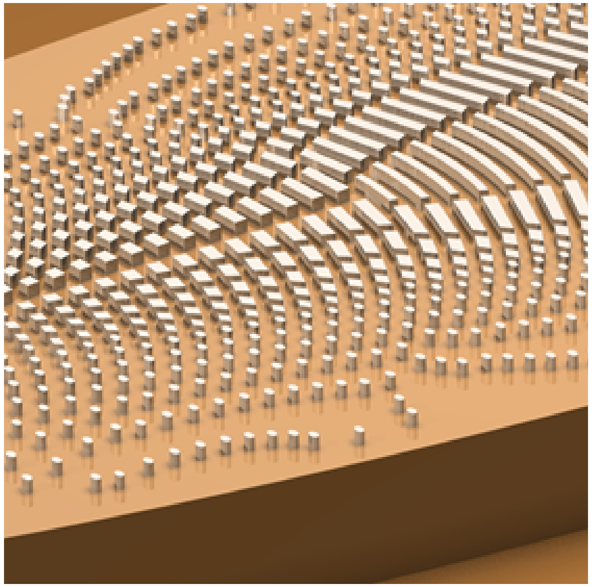
G. Schneider, W. Chao, Y. Suzuki, R. H. Menk Sr., B. Hornberger and many others

A special zone plate

Kipp et al.



transmissive

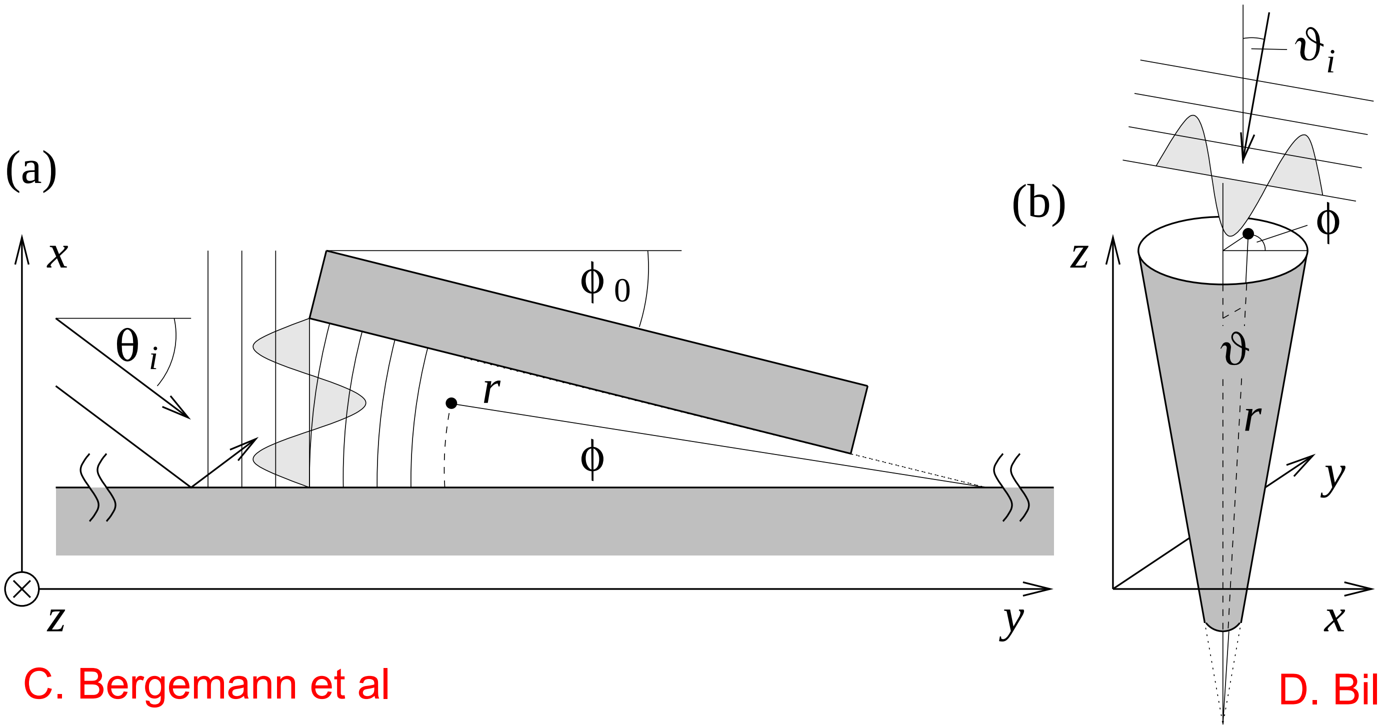


reflective

''Photon sieve''

These zone plates effectively remove subsidiary maxima in the focal plane → enhanced contrast

Wedges and capillaries



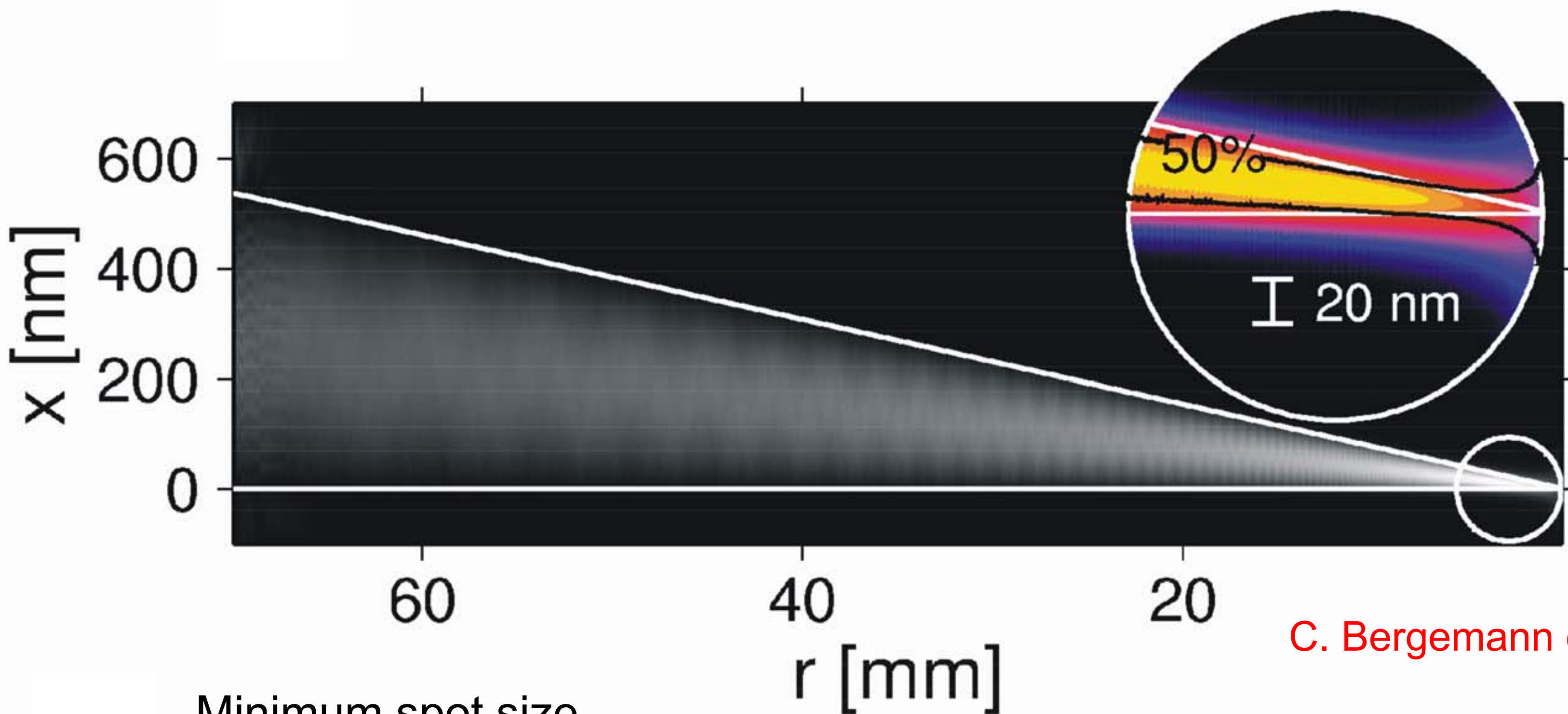
C. Bergemann et al

D. Bilderback et al

Capillaries:

- Squeezes X-ray beams
- Become waveguides for small diameters
- Very small spot sizes are possible
- Coupling into the waveguide critical for efficiency

What is the smallest possible spot size ?



C. Bergemann et al

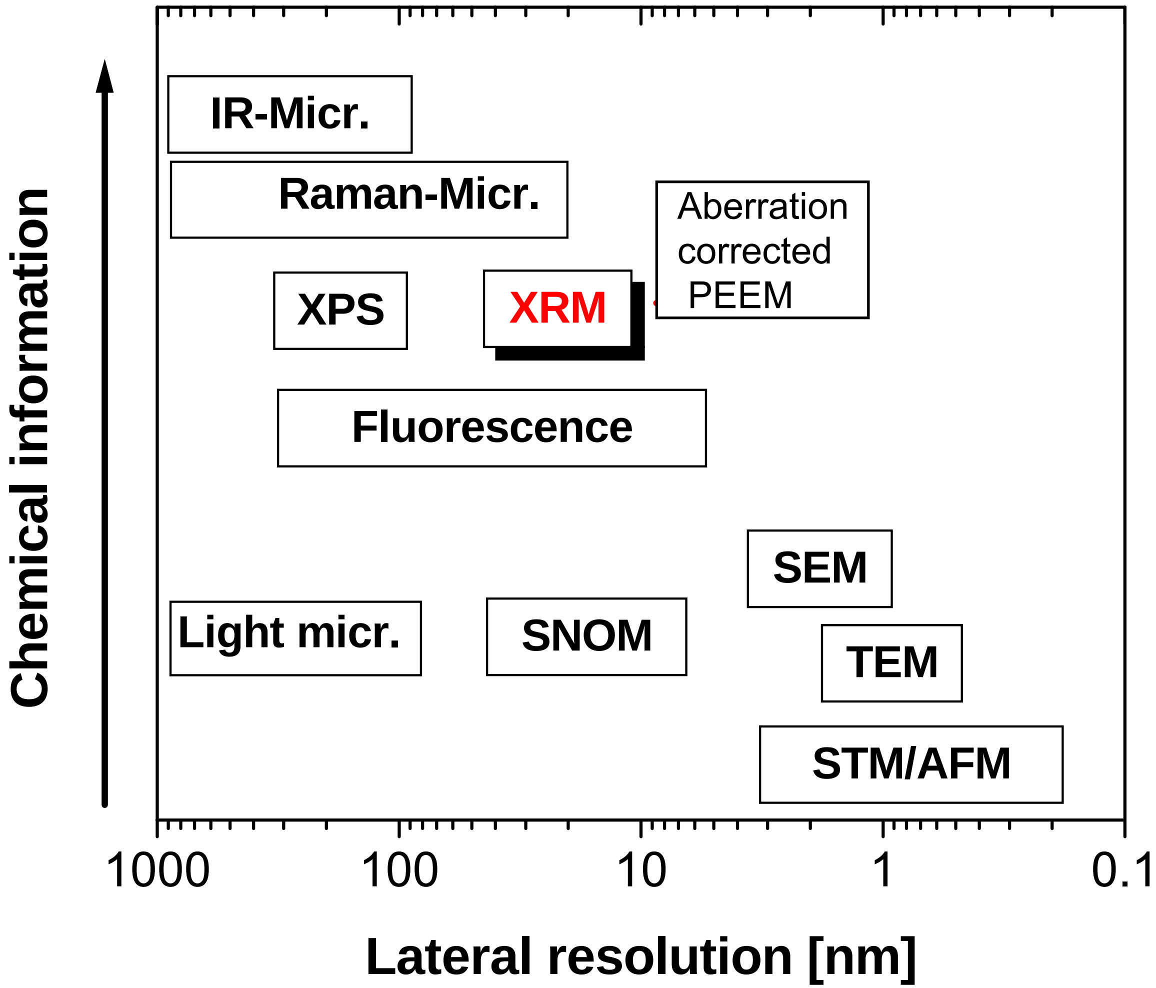
Minimum spot size (FWHM): Δx_{min}=0.64 W_c, with

$$W_c = \frac{\lambda}{2\theta_c} = \frac{1}{2} \cdot \sqrt{\frac{\pi}{r_0 n_e}}$$

SiO_2: Δx_{min} = 13 nm
Au: Δx_{min} = 5 nm

…this limit on spot size appears to hold also for other X-ray focusing devices.

Spectromicroscopic probes



A. Hitchcock

Aberration corrected photoemission microscope

PEEM III
at ALS:

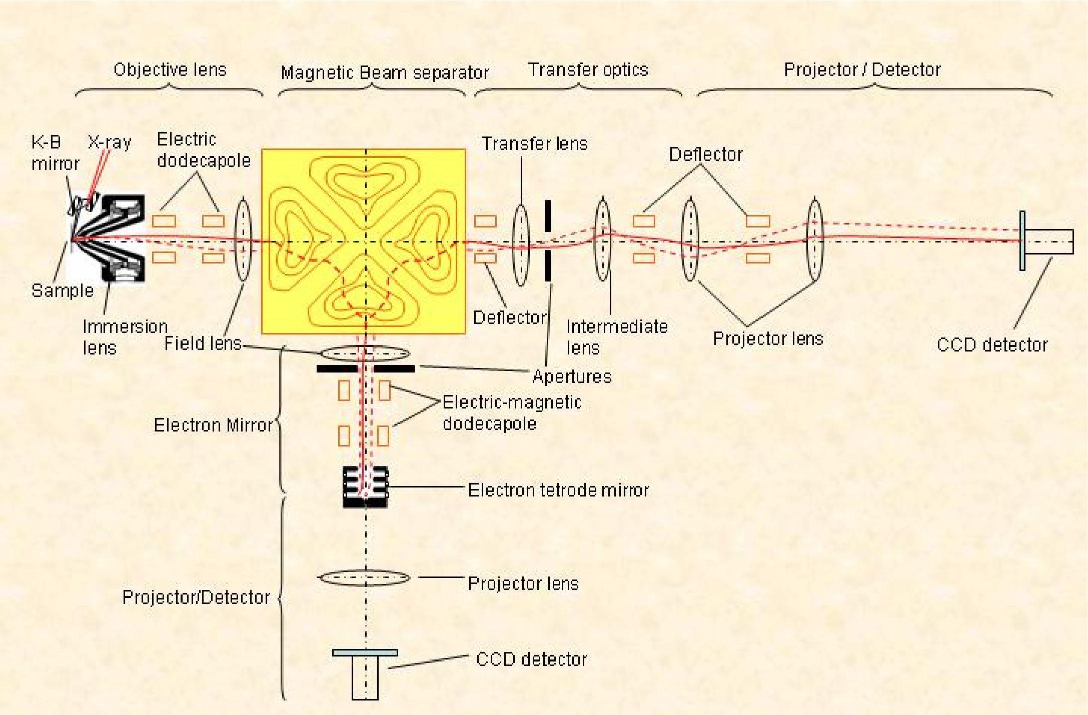


Fig.1 Concept of a X-ray photoemission electron microscope using electron mirror corrector at the ALS

J. Feng et al

At BESSY: SMART project

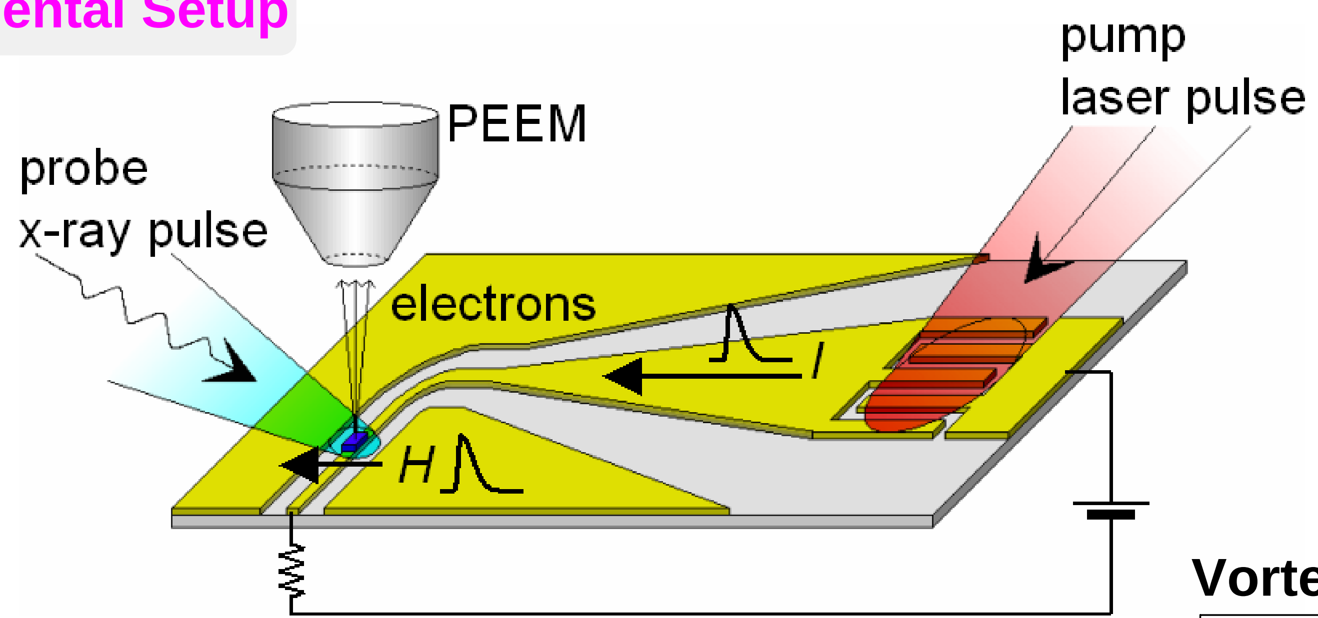
Features:

- Much higher transmission
- Spatial resolution of 5 nm, better than for XRM because of higher *NA* of electron objective lens

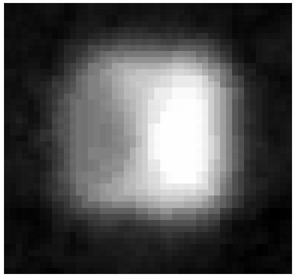
Time Resolved PEEM

S.B. Choe et al

Experimental Setup

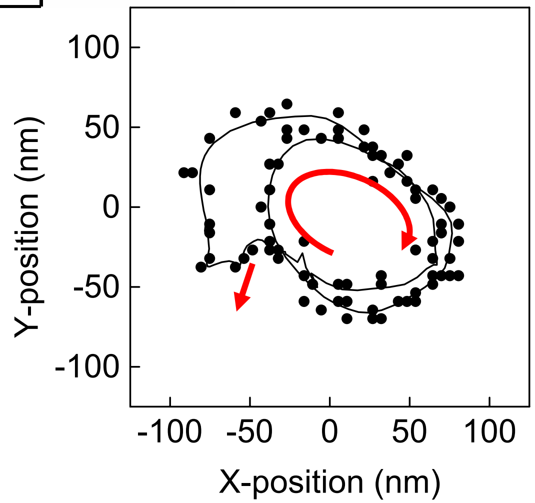


Observation of magnetic vortex dynamics



CoFe Magnetic Pattern of 1 μm x 1 μm

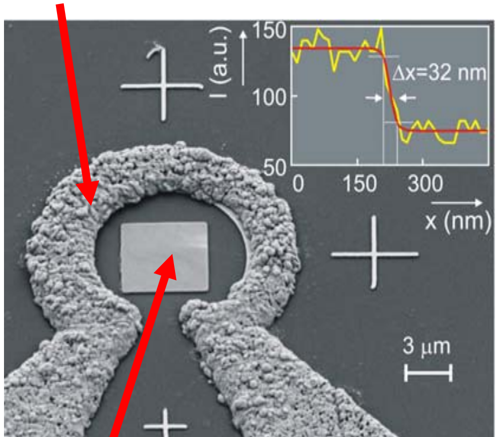
Vortex trajectory



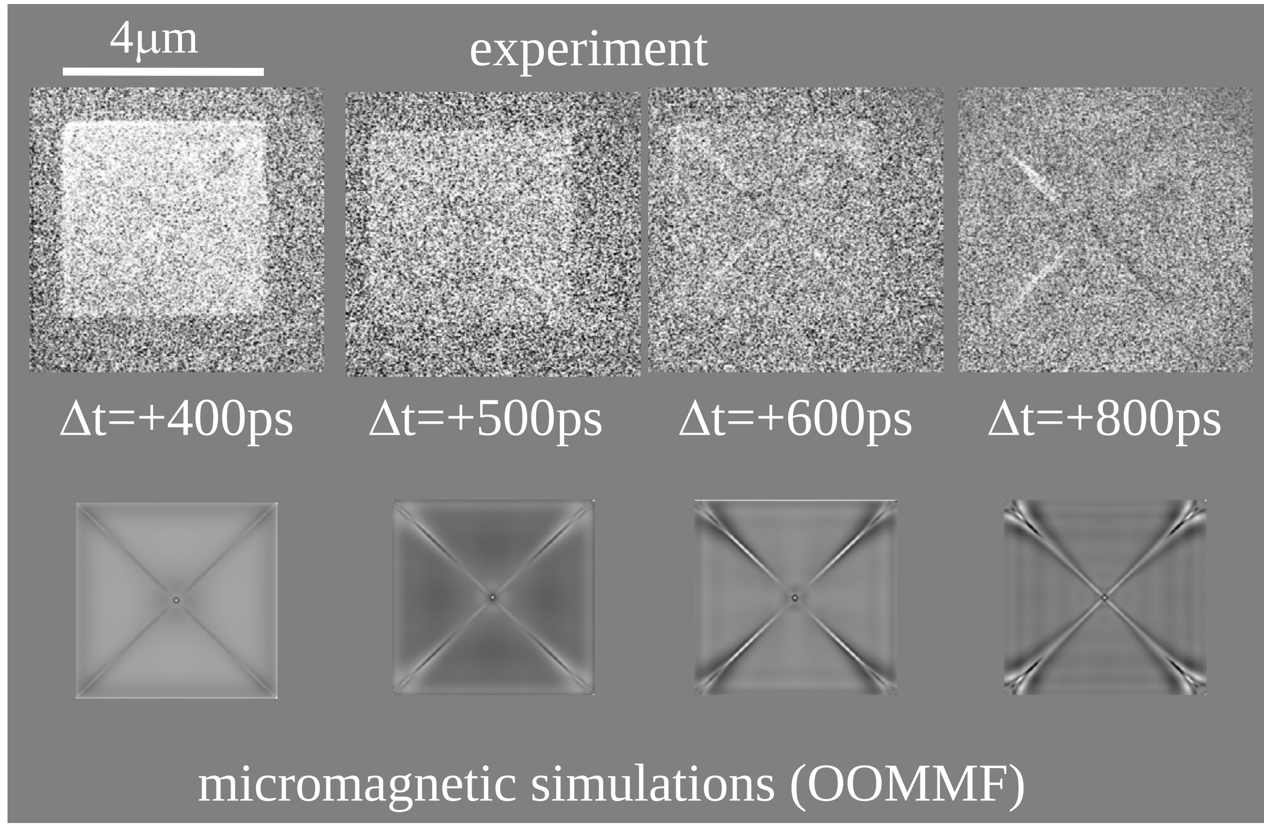
Imaging of ultrafast spin dynamics with Magnetic soft X-ray Transmission Microscopy

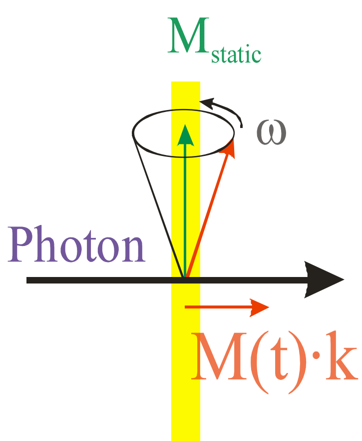
P. Fischer et al

microcoil



sample: 4x4mm^2 PY element





- stroboscopic pump-and-probe technique
- high lateral resolution (<20nm) provided by FZP
- high temporal resolution given by SR pulse width (<100ps)
- inherent chemical sensitivity provided by XMCD magnetic contrast

Future: combine SXTM with streak camera

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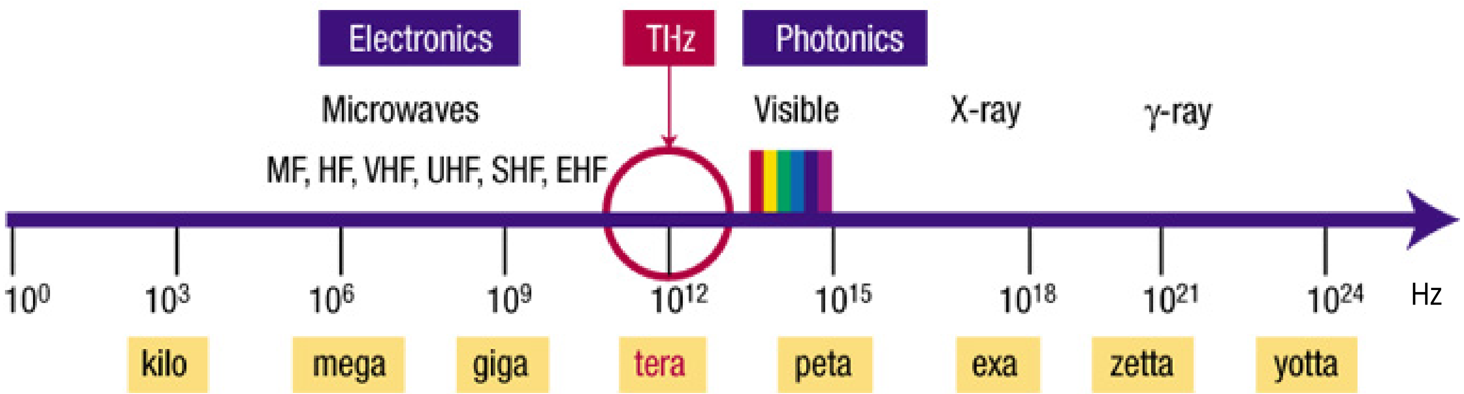
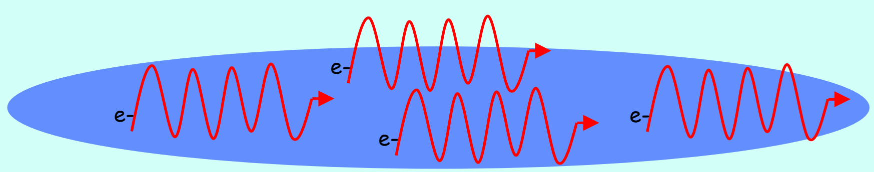
Fully coherent radiation…….

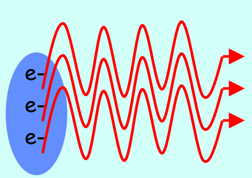
J.M. Byrd



1 THz
= 4.1 meV
= 33 cm^{-1}
= 300 μm



Incoherent emission for long bunches,
P~N



Coherent emission
for short bunches
$P{\sim}N^2$

Achieved at BESSY-II:
10^4 more flux than from
conventional IR sources

Plans for CIRCE @ ALS
$10^6 - 10^{10}$ more flux

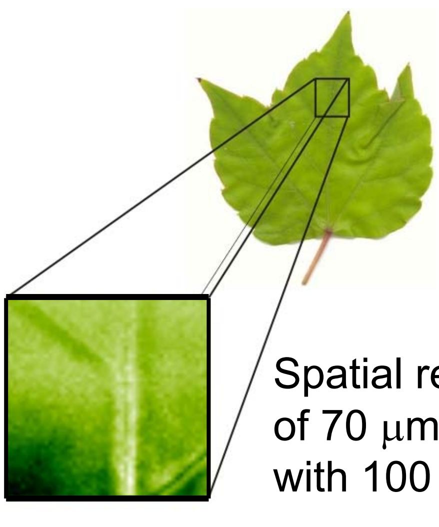
Coherent THz radiation

E.J. Singley, measurements performed at BESSY-II

THz Science:

- collective excitations
- superconductor gaps,
- protein motions & dynamics
- medical imaging

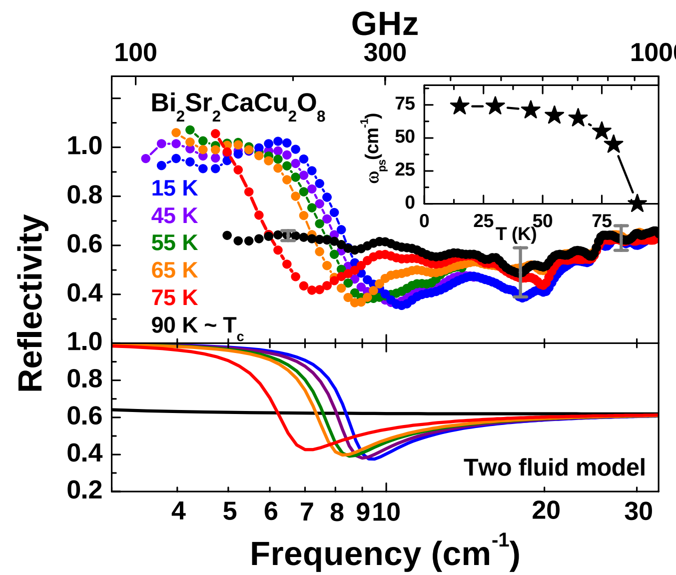
Near-field microspectroscopy on living objects



1 mm

Spatial resolution of 70 μm obtained with 100 μm aperture

Superconductors

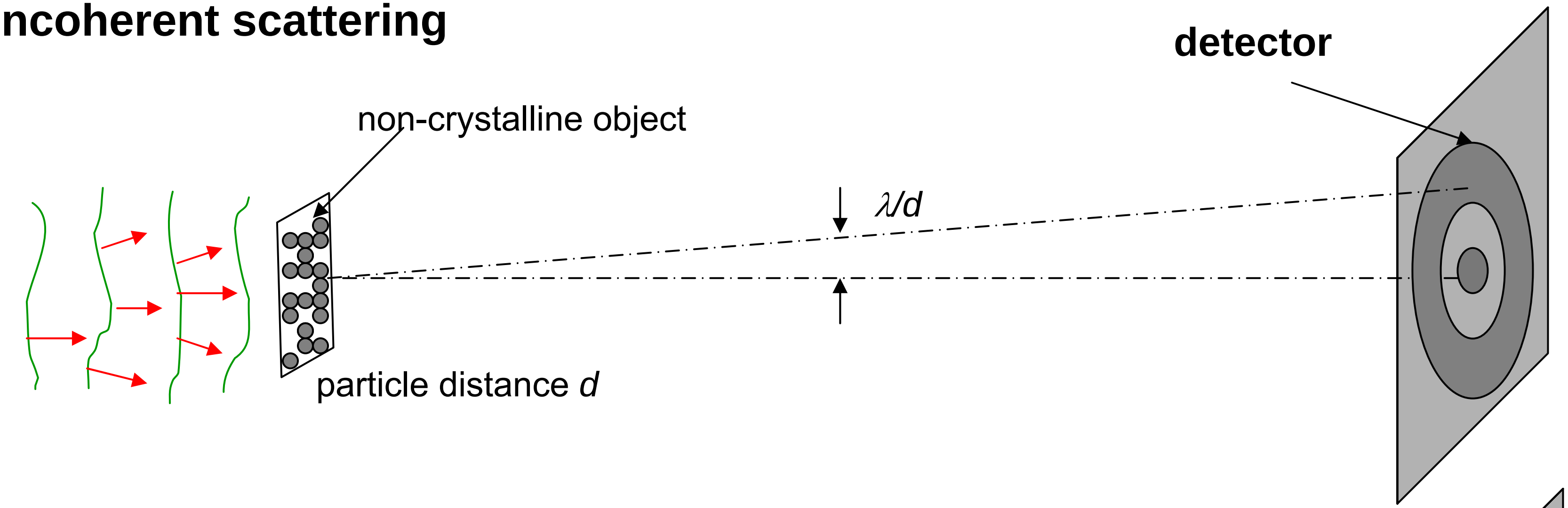


Note:
Near field microscopy
not possible with X-rays, because matter behaves as dielectric for X-rays!

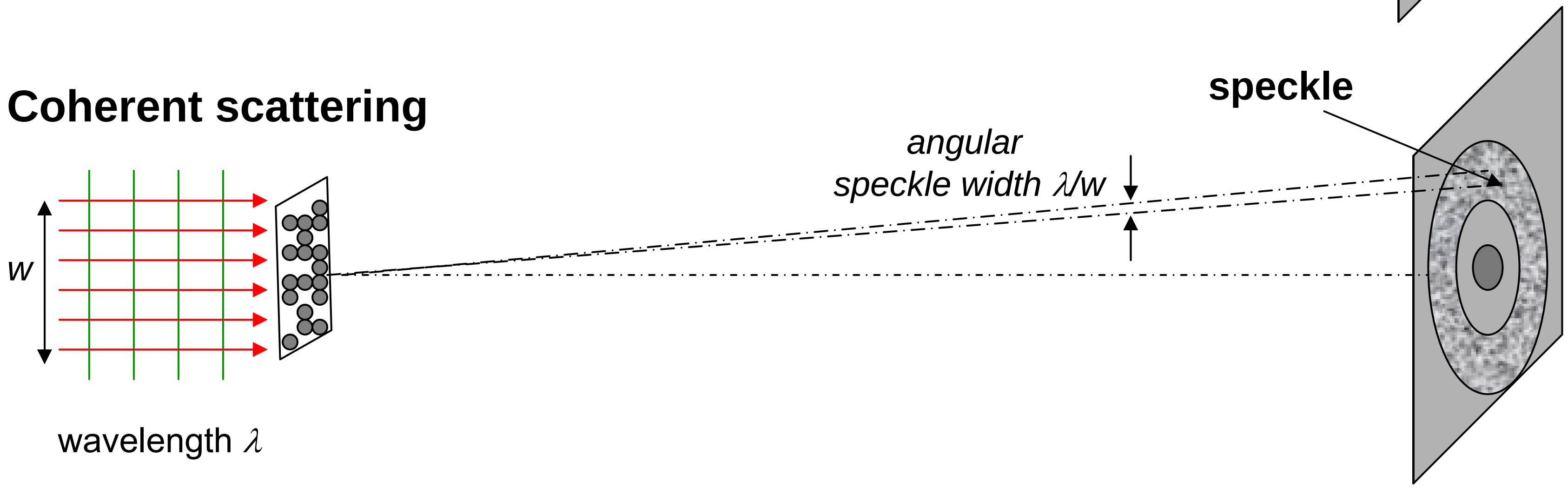
Using the partial coherence of an X-ray beam

Many contributions at the conference and at the workshop

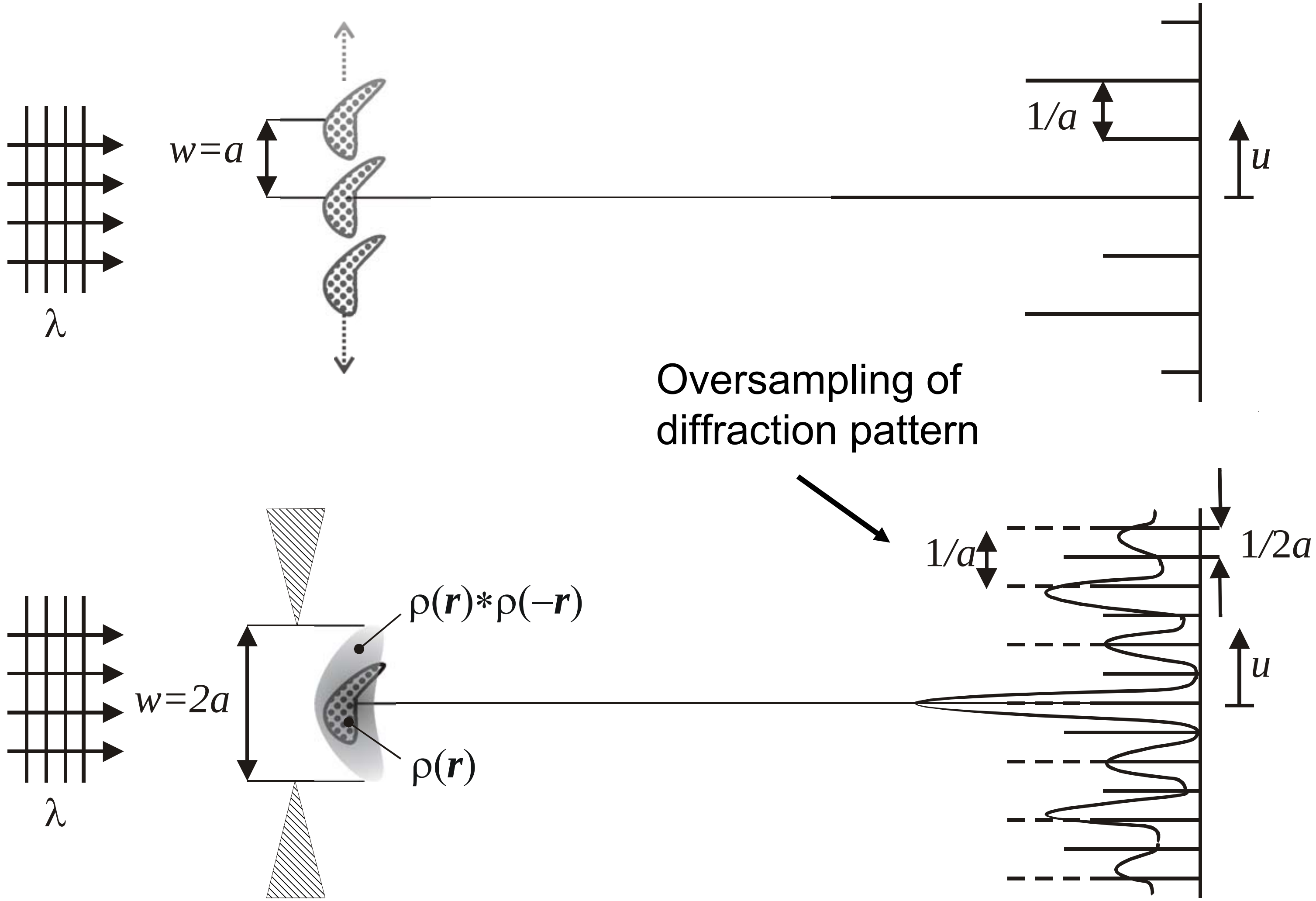
Incoherent scattering



Coherent scattering



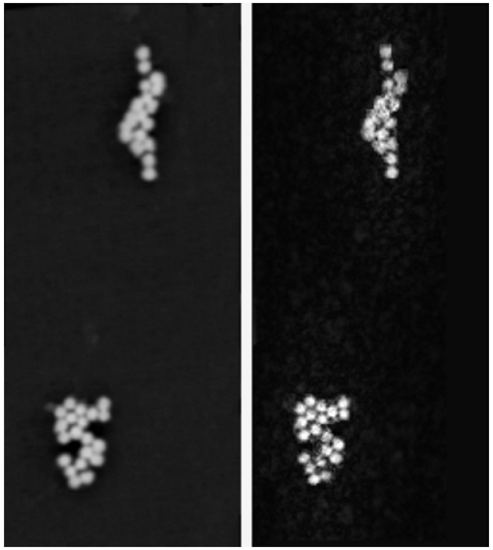
Direct inversion of diffraction patterns
or
'solving the phase problem'



Lensless imaging

See webpages of satellite workshop

Cluster of 50 nm gold balls



J.H. Spence

SEM image **Reconstructed image**

General features:

- **3D reconstructions possible**
- **Depth of field in μm range, i.e. cell dimensions; much better than in TEM**
- **10 nm resolution has been achieved**
- **Ultimate resolution depends on resistance to high radiation does**

But note:

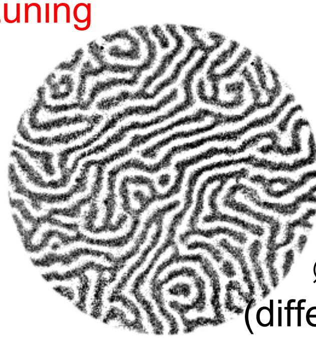
- **Sofar only demonstration expts; but at Spring-8: on bacteria (J. Miao, T. Ichikawa et al)**
- **Electron microscopy still way ahead**

Other uses of coherence

- **X-ray photon correlation spectroscopy**
  Studies of dynamics of (soft) condensed matter
  A. Madsen. G. Grübel et al
  Note: extremely photon-hungry; accessible momentum range limited by count rate
- **Phase contrast imaging, interferometry**
  Many projects at the long beamlines of SPring-8, T. Ichikawa et al
  X-ray Fabry-Pérot for, e.g., metrology: Y. Shyd'ko
- **Sub-ps coherent manipulation**
  B.W. Adams
  Ultrafast X-ray switch?
- **Coherent resonant magnetic scattering in soft X-ray range**
  J. Lüning, J.B. Goedkoop
  Challenge: combine with ps dynamics of magnetic processes

Phase problem can be solved by "oversampling" of speckle image
S. Eisebitt, J. Lüning

Transmission
X-ray
Microscope



"Best"
Reconstruction
from
Speckle Intensities

∅ 5 μm
(different areas)

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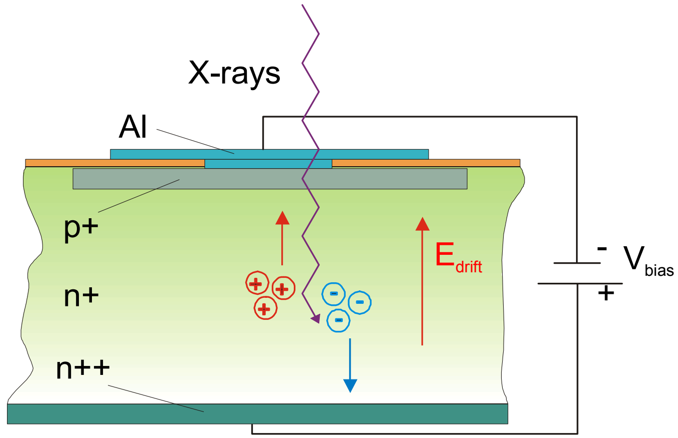
  Not true for G. Derbyshire

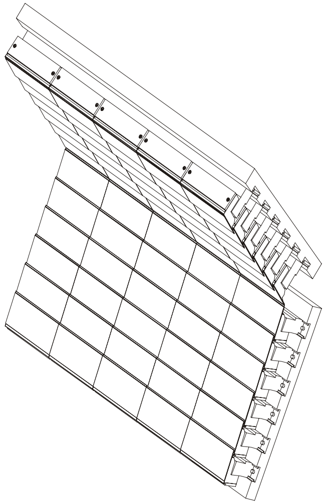
Pixel Detectors

G. Hülsen, C. Brönnimann et al

Si pn-junction

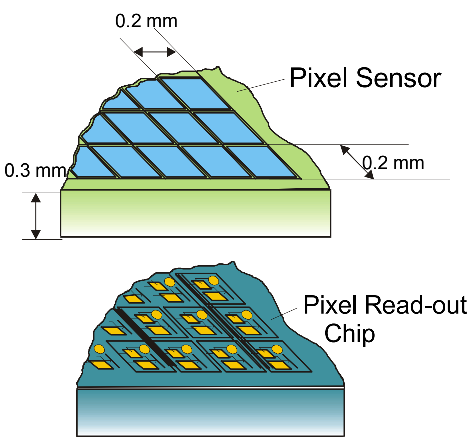
3.6 eV to create
1 eh-pair

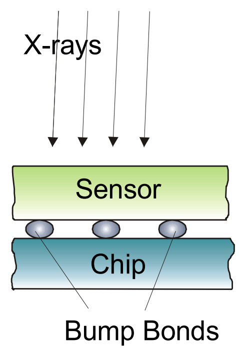




Specs of SLS pixel detector

- Size: 40 x 40 cm2 (0.16m^2)
- 2000 x 2000 pixels
- Pixel size: 200 x 200 μm^2
- Modular detector -> dead area ~6%
- High frame rate: >10Hz
- High duty cycle: <6% (Tro~6ms)





Next steps:

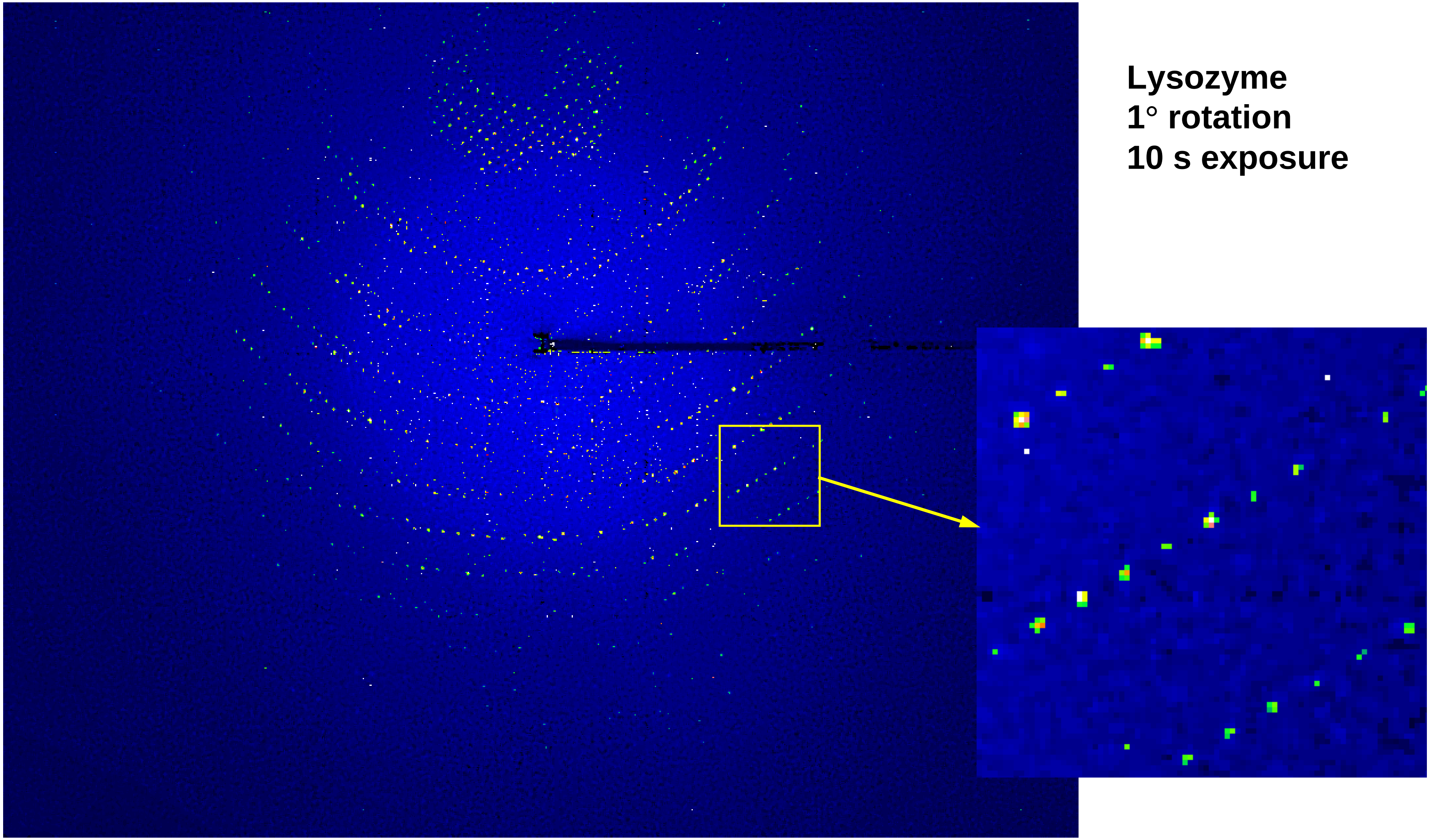
- Energy and time stamping
- Cross correlation of pixels in spatial and temporal domains

Major initiatives at several SR facilities are now underway

SLS pixel detector

PX at Spring-8, BL38B1

E. F. Eikenberry et al



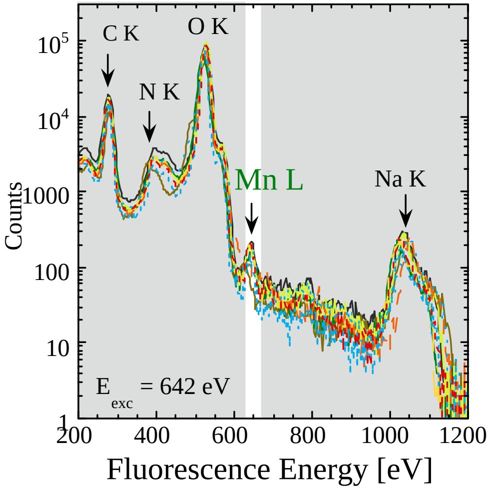
Lysozyme
1° rotation
10 s exposure

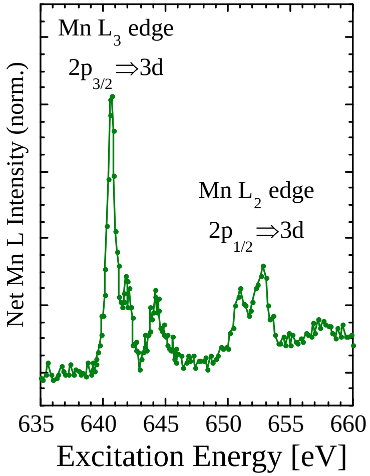
Inventive detection and measurement methods

X-rays

- Superconducting junction X-ray detectors
  S. Friedrich. *Suited for fluorescence detection*
- A special method for detecting moving biomolecules
  Y.C. Sasaki
- Inelastic soft X-ray scattering
  H.S. Fung: resolving power of 3×10^4 at 400 eV!
  Other novel X-ray/VUV spectrometers: J. Guo, N. Kosugi, A. Tagliaferri, and C. Masciovecchio and others

Mn in oxygen-evolving complex in photosystem II





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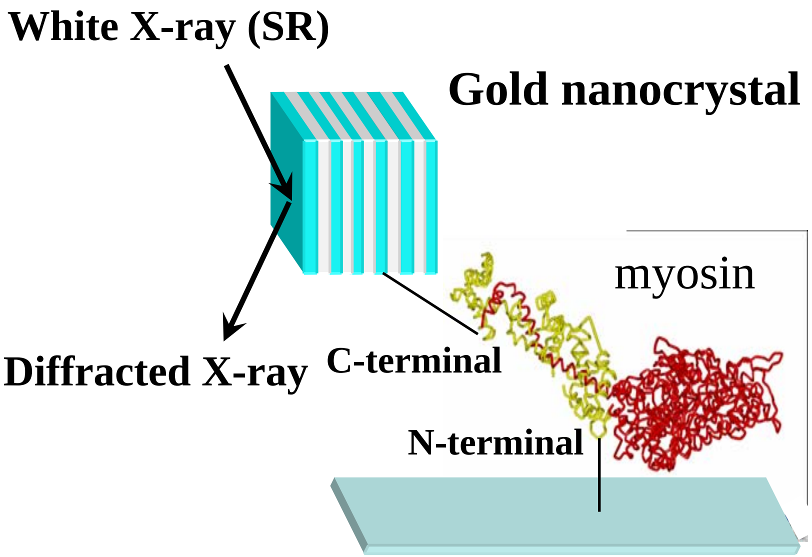
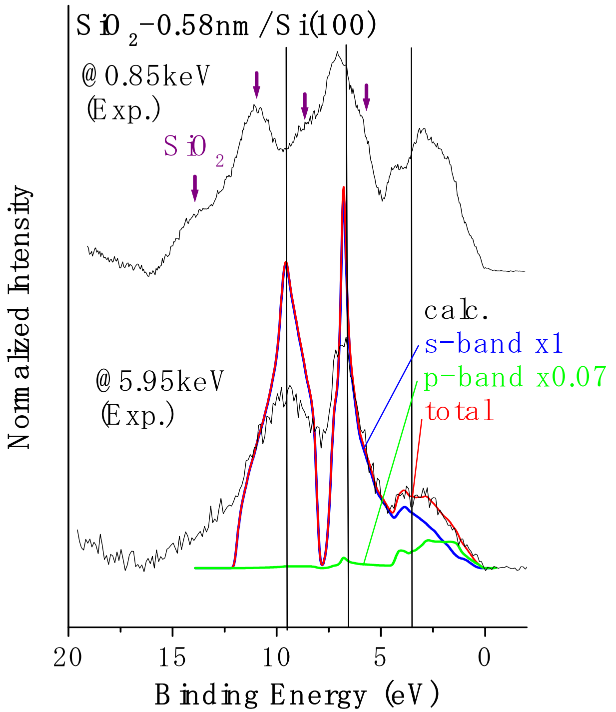


Inventive detection and measurement methods

Electrons

- High kinetic energy photoemission
  Important for bulk sensitivity in studies of electronic materials properties
  Y. Takata, G. Paolicelli
  Count rates very low!
- New 1D and 2D electron detectors
  P. Denes



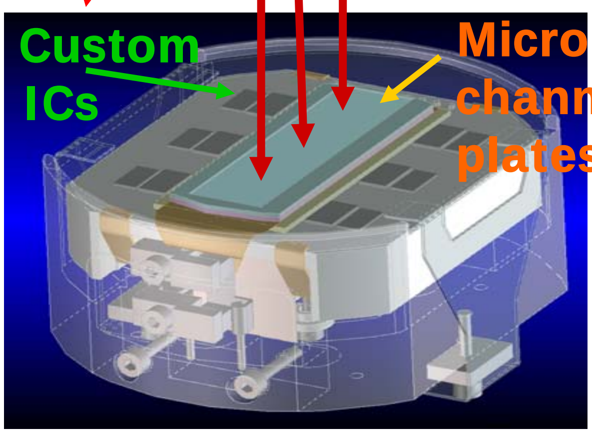
Probe depth @ 6 keV > 10nm
Contribution of surface SiO_2 is negligible

Inventive detection and measurement methods

Electrons

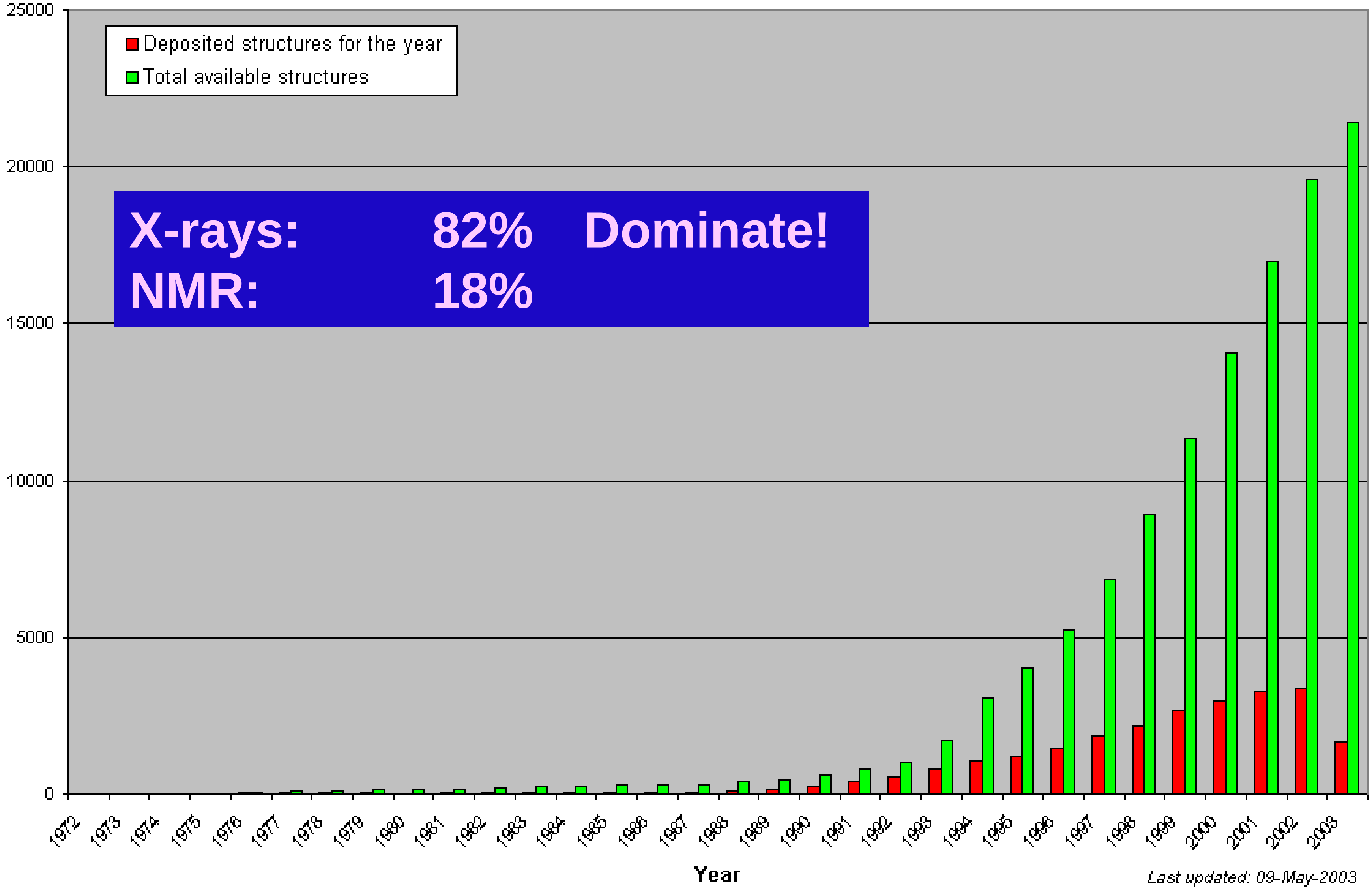
- High kinetic energy photoemission
  Important for bulk sensitivity in studies of electronic materials properties
  Y. Takata, G. Paolicelli
  Count rates very low!
- New 1D and 2D electron detectors
  P. Denes

e^- or $h\nu$



- >2 GHz overall linear count-rate→
- spectral readout in 60 μs→
- time-resolved measurements
- programmable, robust
- Sized to fit existing spectrometers (Scienta, PHI, ...)

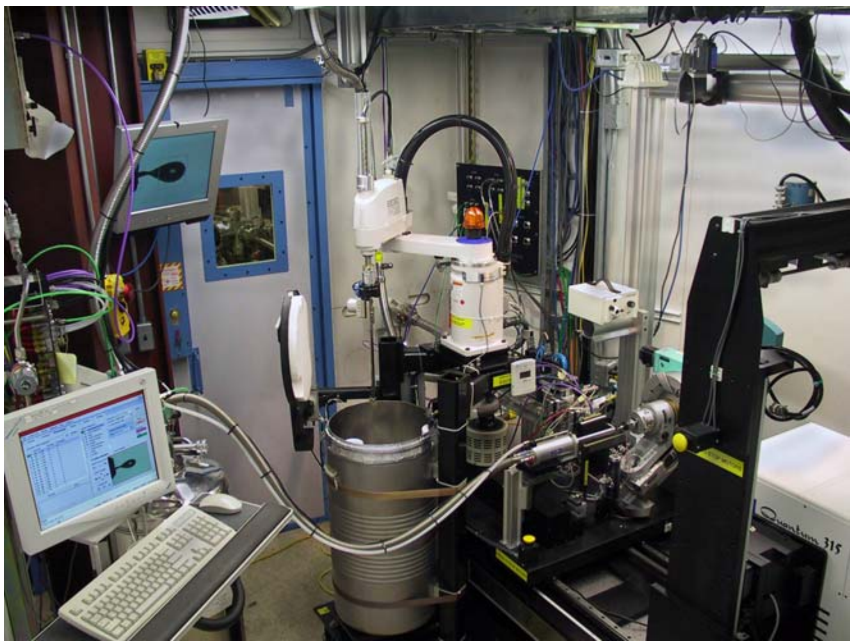
Spectacular growth of structural biology

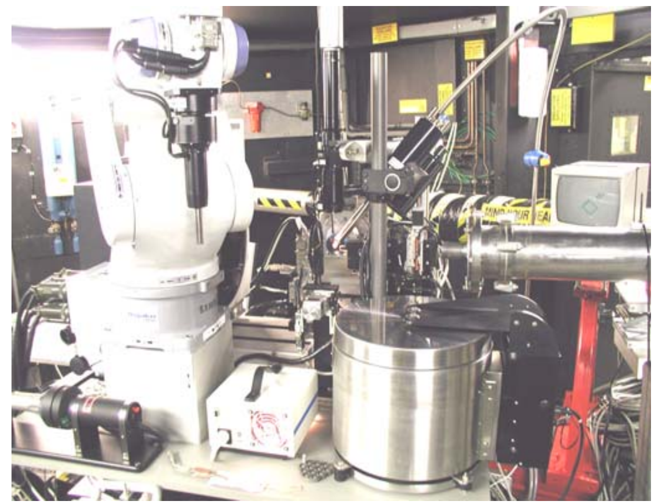


Automation of PX facilities

C. Nave, M. D. Miller, N. K. Sauter

SSRL Beamline 11-1





SRS Daresbury

Need for standardization !

Filling the gap between the third and fourth generation

- We have no problem filling that gap!
- Each three years (SRI cycle) we win at least an order of magnitude in *flux, brilliance, coherence, time resolution*
- New SR facilities are very sophisticated
  Upgrades of existing facilities are underway
- The future of the next generation looks *brilliant*

The instrumentation scientists *make it all happen!*